LA-UR-21-23883
Approved for public release; distribution is unlimited.

Title: Software on Mars

Author(s): Michel, John M.

Intended for: Community outreach. Presentation for high school students.

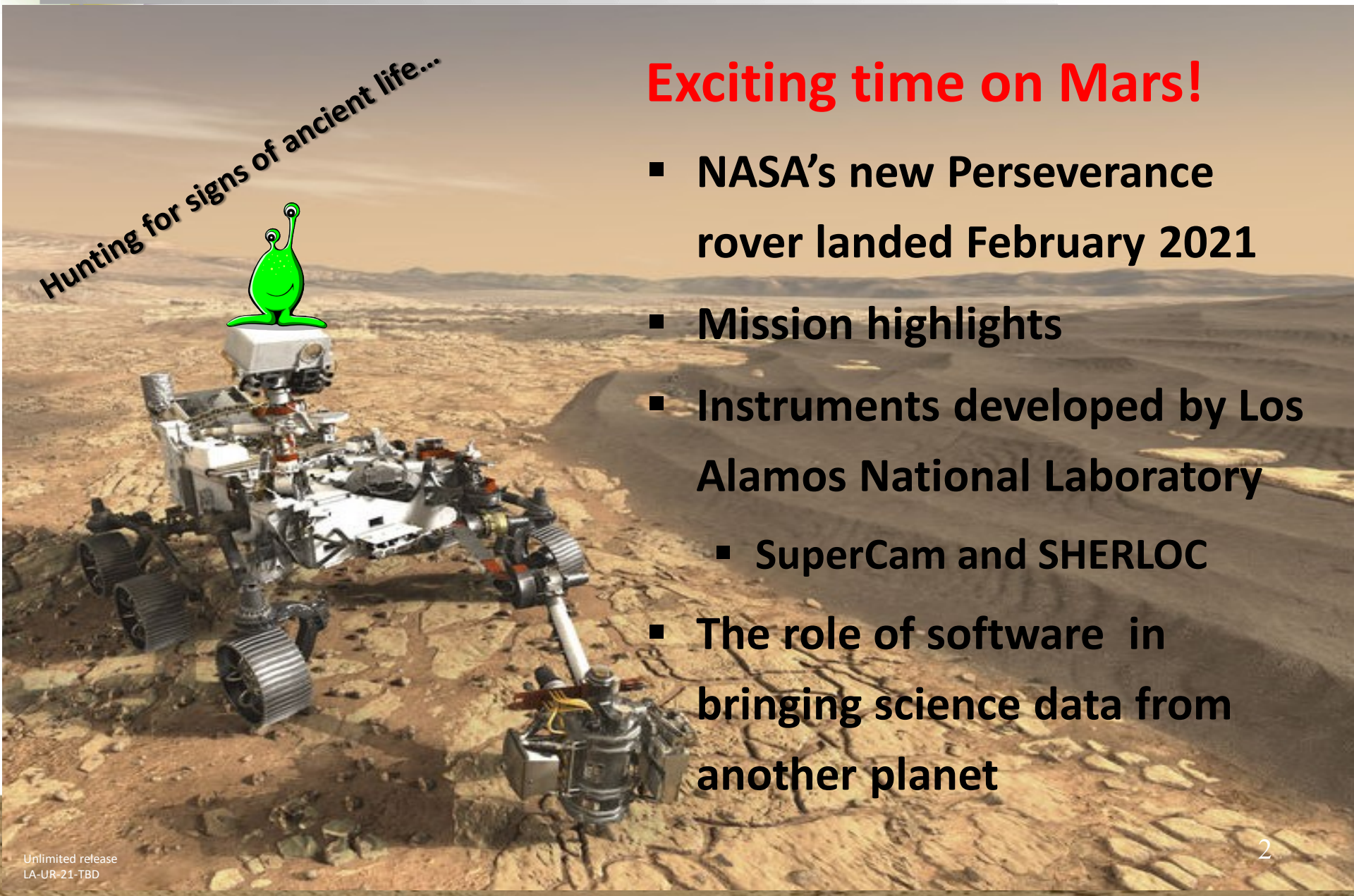
Issued: 2021-04-21

Software on Mars

John Michel
Los Alamos
NATIONAL LABORATORY

Unlimited release
LA-UR-21-TBD

Outline



Exciting time on Mars!

- NASA's new Perseverance rover landed February 2021
- Mission highlights
- Instruments developed by Los Alamos National Laboratory
  - SuperCam and SHERLOC
- The role of software in bringing science data from another planet

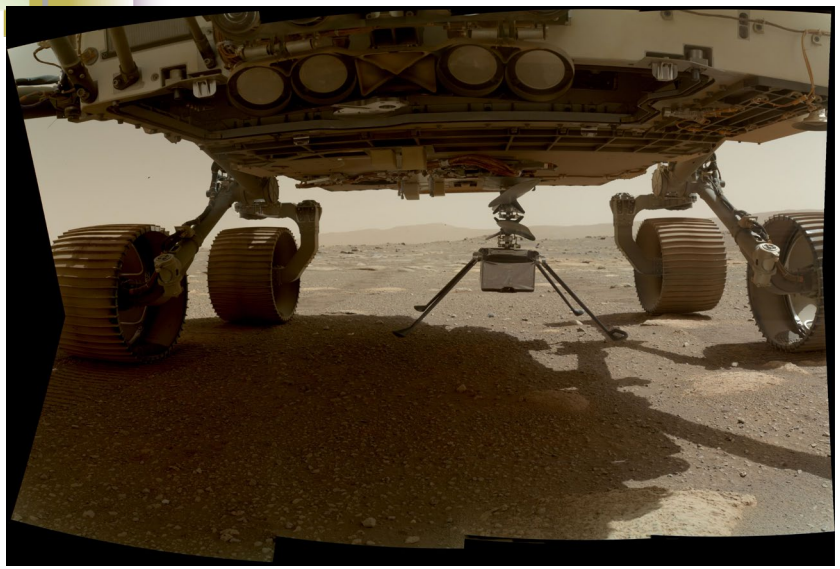
Landing Animation

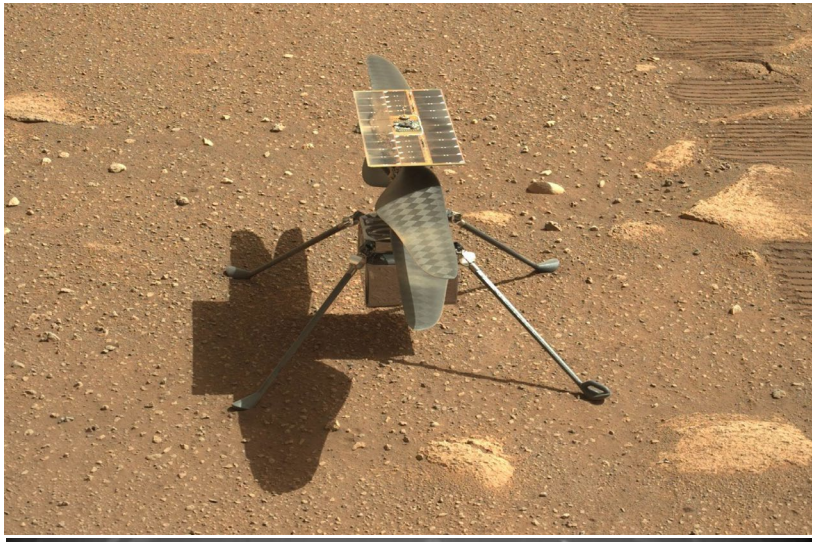
NASA publically available video animation of rover landing
https://www.youtube.com/watch?v=rzmd7RouGrM

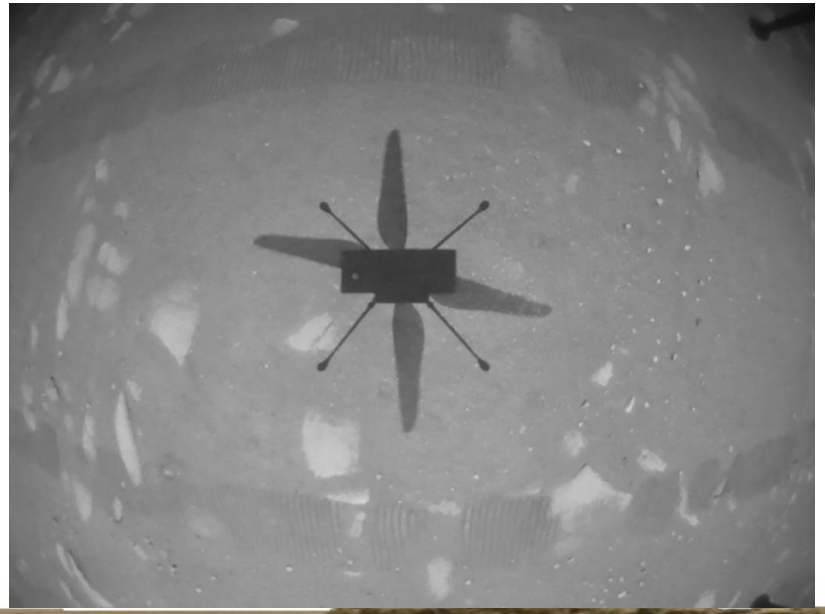
Mission Highlight so far…

- All the instruments checked out and ready to roll !!!

Helicopter



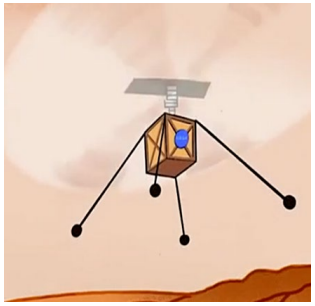




Helicopter Software Flexibility

Helicopter software ‘watchdog’ rebooted the helicopter before transitioning to flight mode

If software doesn’t keep telling the hardware it’s alive, the watchdog will bite and reboot the system!

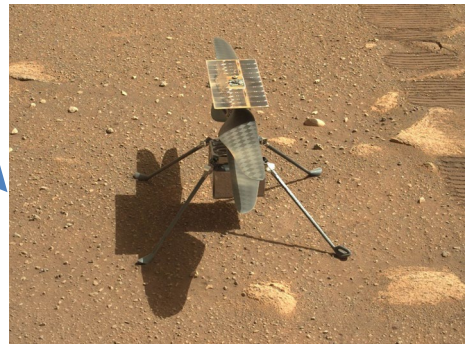


Software design flexibility allowed patch to be transmitted to Mars

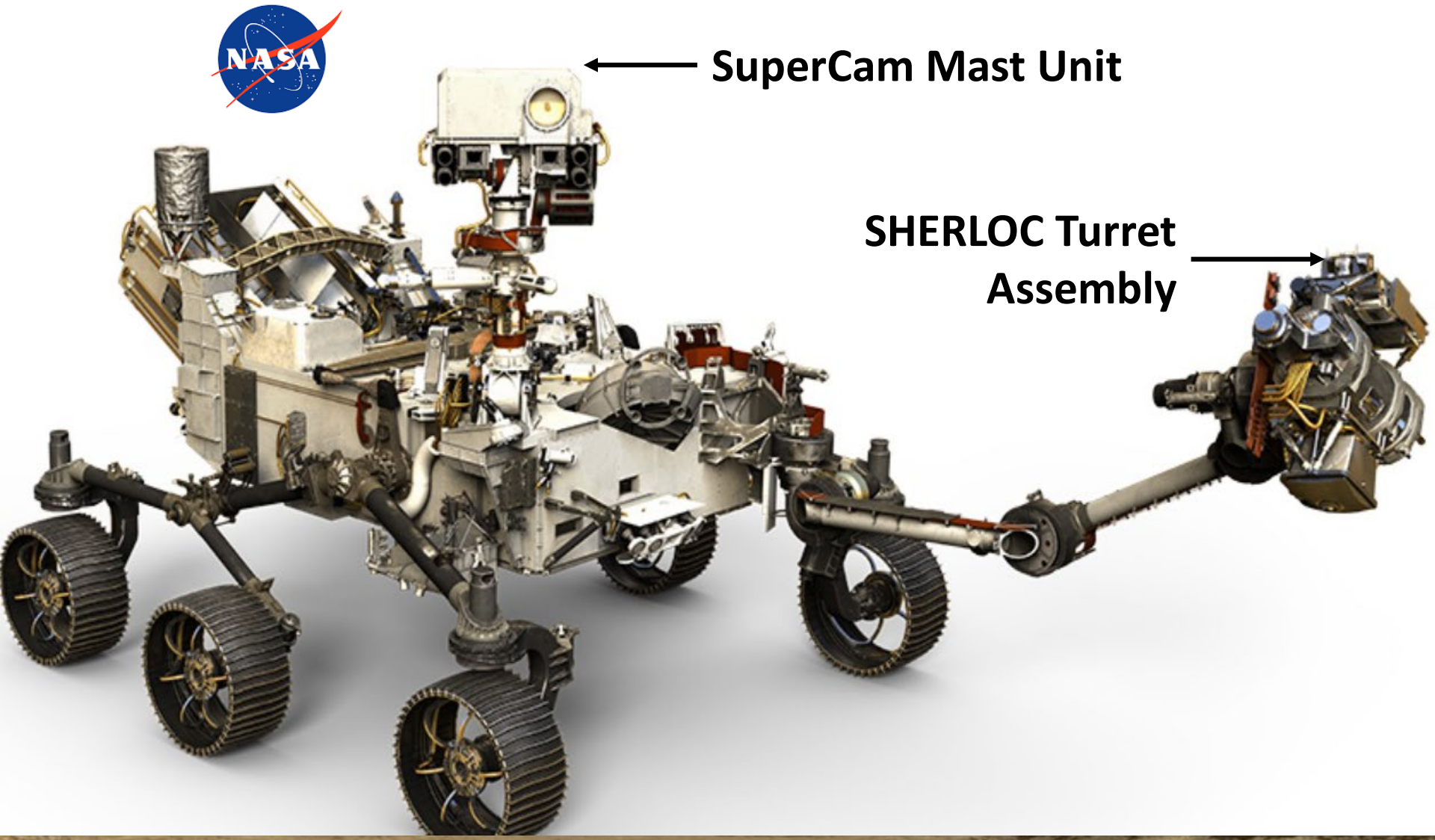
Helicopter Software

180 Million Miles!

Qualcomm Snapdragon 801 processor with a Linux operating system.



Mars2020 Perseverance Rover



SuperCam Instrument

Mast Unit built by the French Space Agency CNES

Body Unit built by Los Alamos National Laboratory

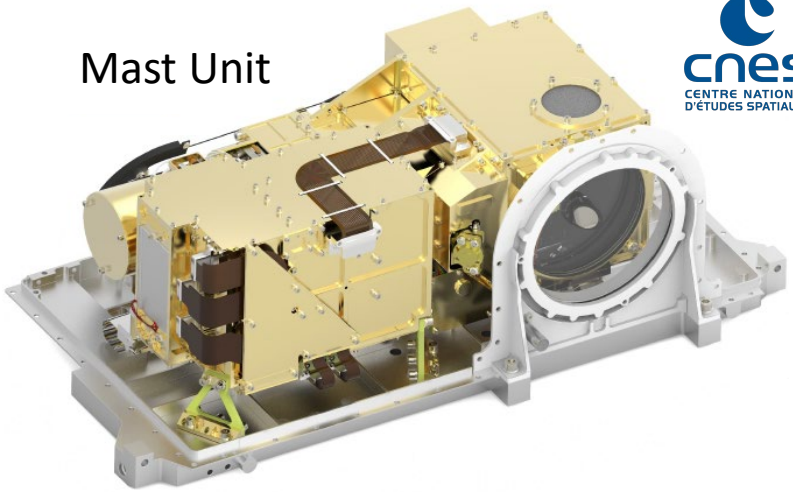
Designed to perform chemical analysis of targets up to 21 feet away

- Laser Induced Breakdown Spectroscopy (LIBS) and microphone
- Raman/Fluorescence Spectroscopy
- Visible and Infrared Spectroscopy
- Color Remote Micro Imaging

Mast unit contains lasers, telescope, IR spectrometer, imager, and microphone

Body unit contains three spectrometers, main processor, and rover communications

Mast Unit



Body Unit

SHERLOC Instrument

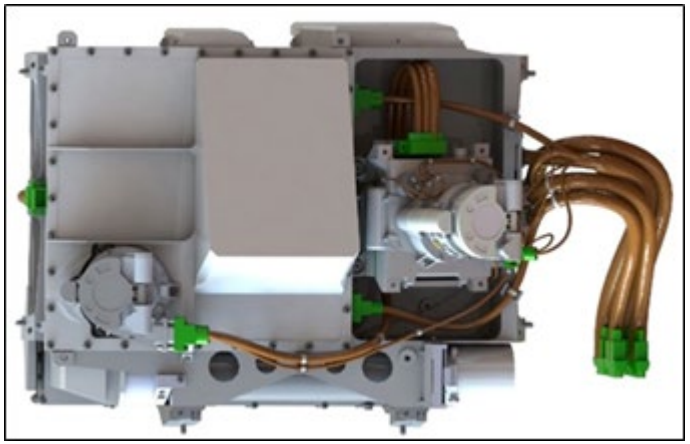
Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)

New rover instrument lead by JPL

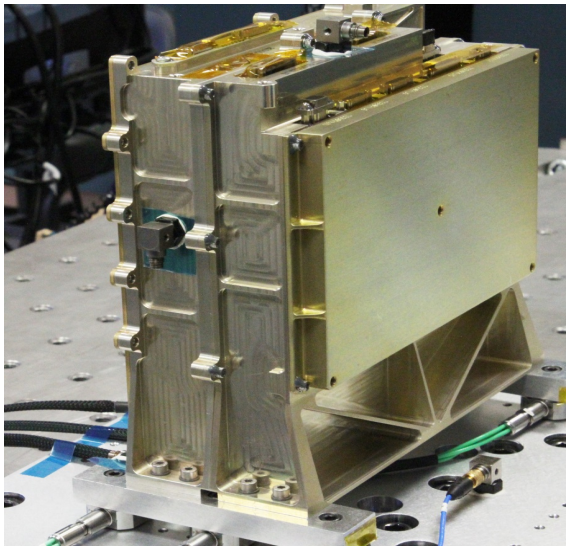
LANL provided spectroscopy electronics subsystem and flight software

Designed to analyze organic chemicals at a microscopic scale

- Raman/Fluorescence Spectroscopy focused on organics at micro-scale
- Scanning mirror
- UV laser
- Onboard spectra analysis



Arm mounted laser and optics

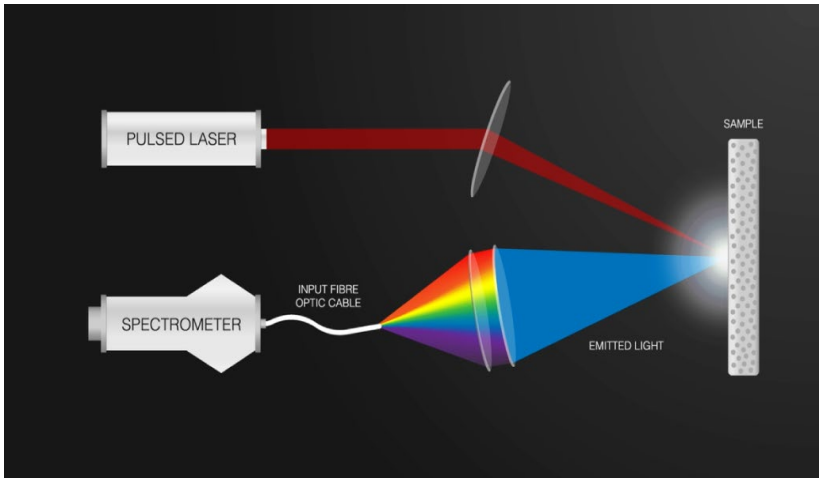


Rover mounted spectrometer electronics with CPU

LIBS and Raman Spectroscopy

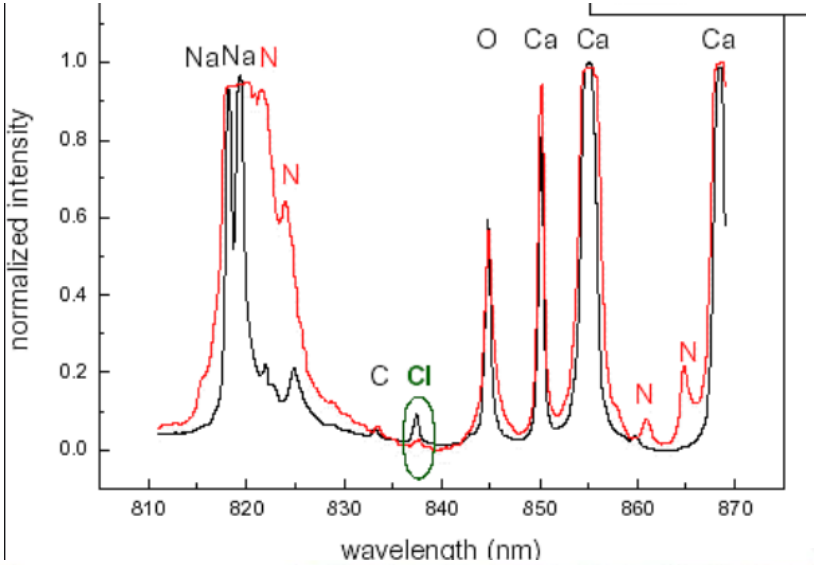
LIBS (laser induced breakdown spectroscopy)

- Focused high energy laser blasts atoms causing electrons to jump to higher orbit
- Wavelength of light generated by electron change of state tells us the element(s) present in the sample



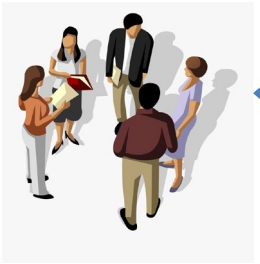
Raman spectroscopy

- Similar to LIBS however laser is not focused and is used to excite molecules
- Different wavelengths of laser can reveal complex molecules containing carbon



Software Commanding and Data Collection

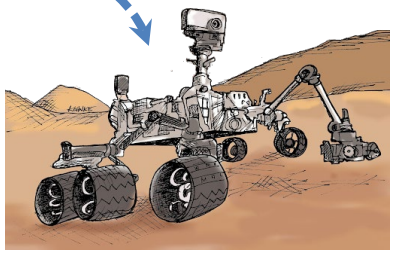
- Software is critical to brining scientific ideas to life



Science and operation team analyze data and develop plan

Command
CONFIGURE_CCD_TIMING
CONFIGURE_CCD_REGIONS
CONFIGURE_INTENSIFIER
CONFIGURE_HVPS
DO_SPECTRA
MU_CONFIGURE_AUTOEXPOSURE
MU_TAKE_RMI_IMAGE

Sequence of commands



Instructions uplinked to the Rover

Rover and instrument software execute commands, collect data, and return science to earth

Space Computing Technology

- **Space is a challenging environment for electronics**
- **Radiation hardened components must be used**

Processor:

- Cobham Gaisler radiation hard 32 bit LEON3 processor running at 50 MHz

Field Programmable Gate Array (FPGA):

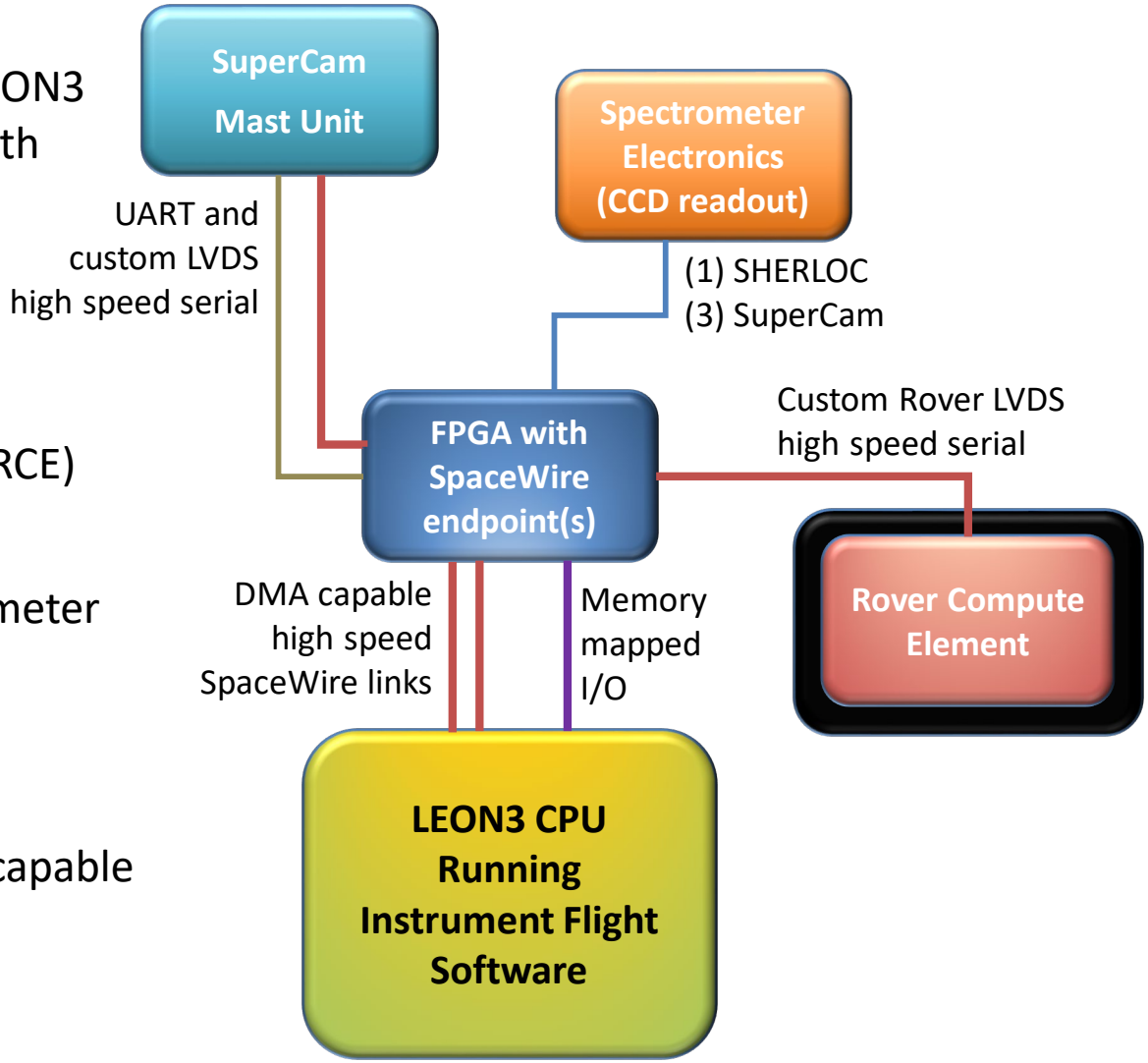
- Create an integrated circuit that can be changed
- Used for very precise timing, specialized communication interfaces, signal processing, etc.
- SuperCam and SHERLOC used to read out Charged Couple Device (CCD) to produce spectra

Hardware and Software

Custom LANL designed rad hard LEON3 based processor board used for both instruments

- Actel FPGA
- 250 MB SDRAM
- Rover compute element (RCE) interface
- SpaceWire based spectrometer interfaces

FPGA firmware includes spacewire endpoint to convert Mast Unit and Spectrometer electronics to DMA capable SpaceWire



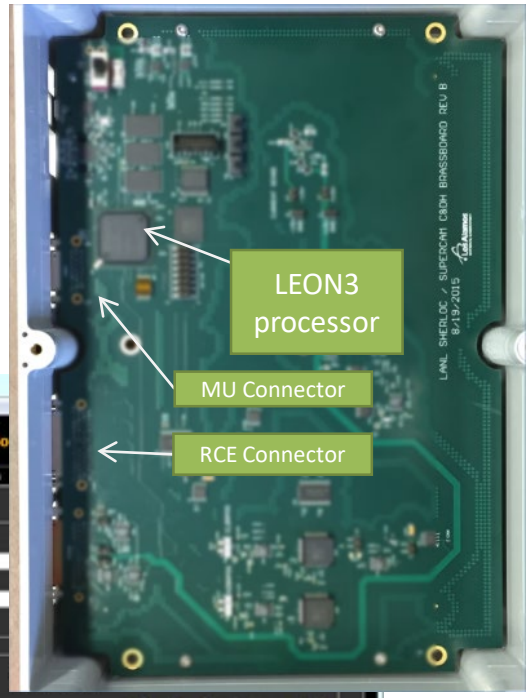
Software Development

- Both instruments approximately 13 KLOC
  - Small and reliable
- C99 programming language
- Board support package and modified GCC compiler by Cobham Gaisler
- VxWorks operating system
- Coverity static code analysis
- Test Anything Protocol (TAP) unit testing
- Custom Python scripted functional testing
- Jenkins nightly build and test

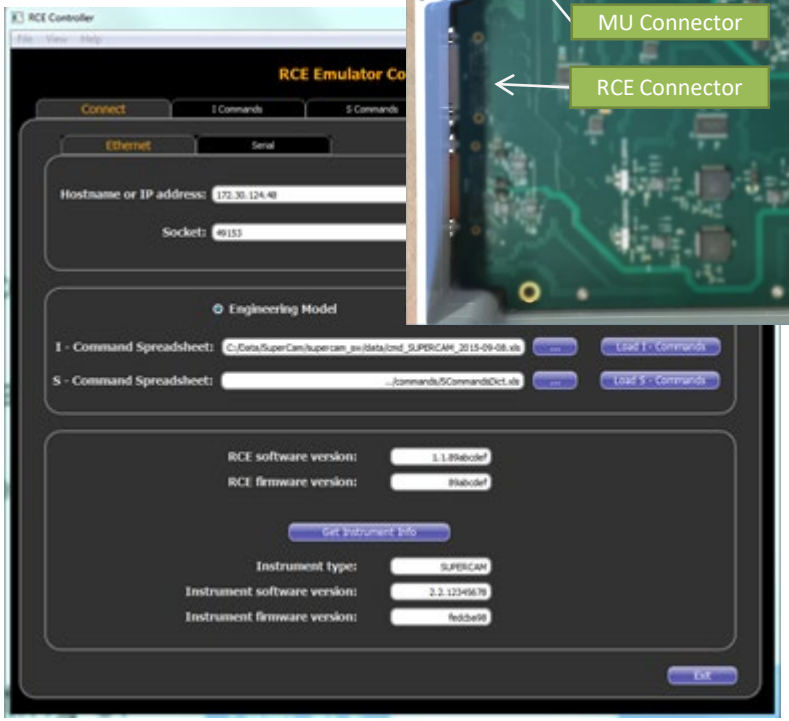
Software Development and Test

- Very early created inexpensive ‘prototype boards’ with LEON3 instantiated in a Xilinx FPGA
- Provided ubiquitous software and firmware development and test platforms that works with the custom interfaces
- With minor software and firmware changes, the same prototype board is used as rover and SuperCam mast unit emulators
- Python based command and telemetry software user interface to complete RCE emulator

FPGA based brass board

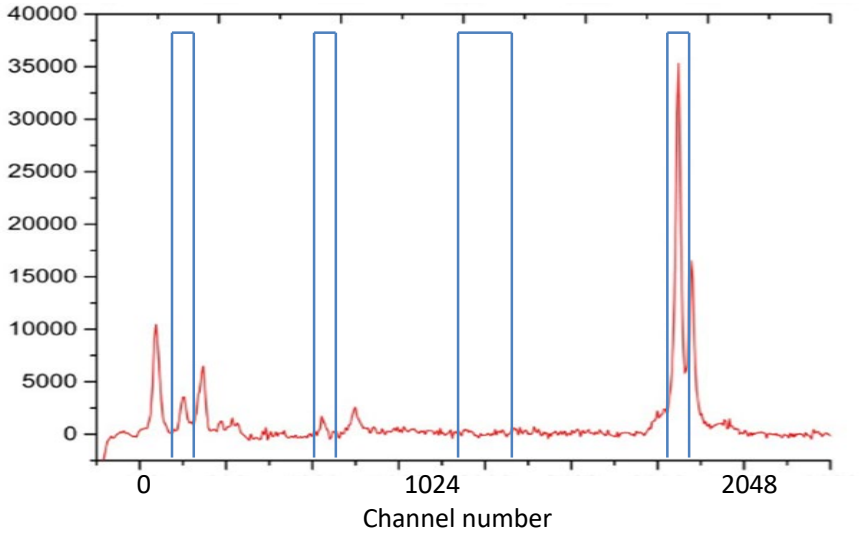


User Interface SW



SHERLOC Advanced Software

- Using a scanning mirror, SHERLOC gathers hundreds of spectra in a coarse pre-defined pattern
- Instead of sending all the spectra back to Earth, go back to the 'most interesting' point and perform a fine scan
- However spectra processing must be done for accurate analysis
  - Background subtraction
  - Bad pixel removal
  - Laser normalization
  - Cosmic ray removal



Science team defines weighted regions of channels (blue lines)

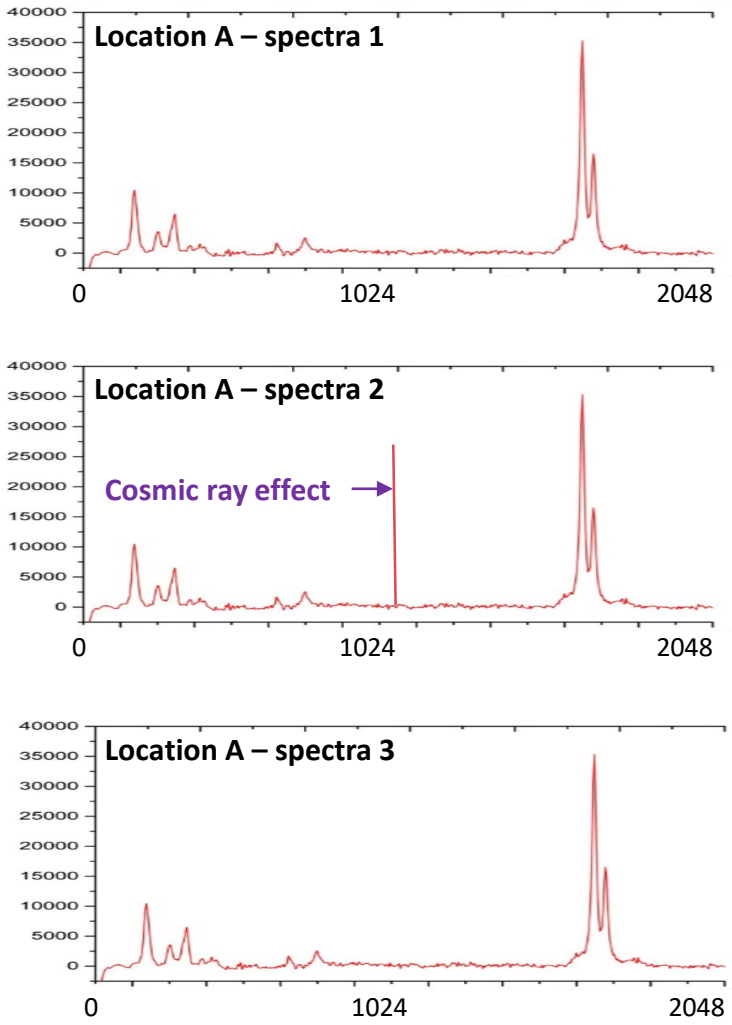
Spectrum with greatest weighted intensity summed from those regions considered 'most interesting'

SHERLOC software automatically goes back to that spectrum location

SHERLOC Advanced Software

Cosmic Ray Removal

- Cosmic ray's affecting CCD data can cause erroneous analysis results
- Multiple spectra are gathered from one spot
- Data for each wavelength channel is analyzed
- JPL developed statistical analysis technique implemented in flight software used to find outliers
  - Sigma clipping plus Freedman-Diaconis rule
- Demonstrated very large datasets (1296 spectra take ~5 minutes on flight processor)

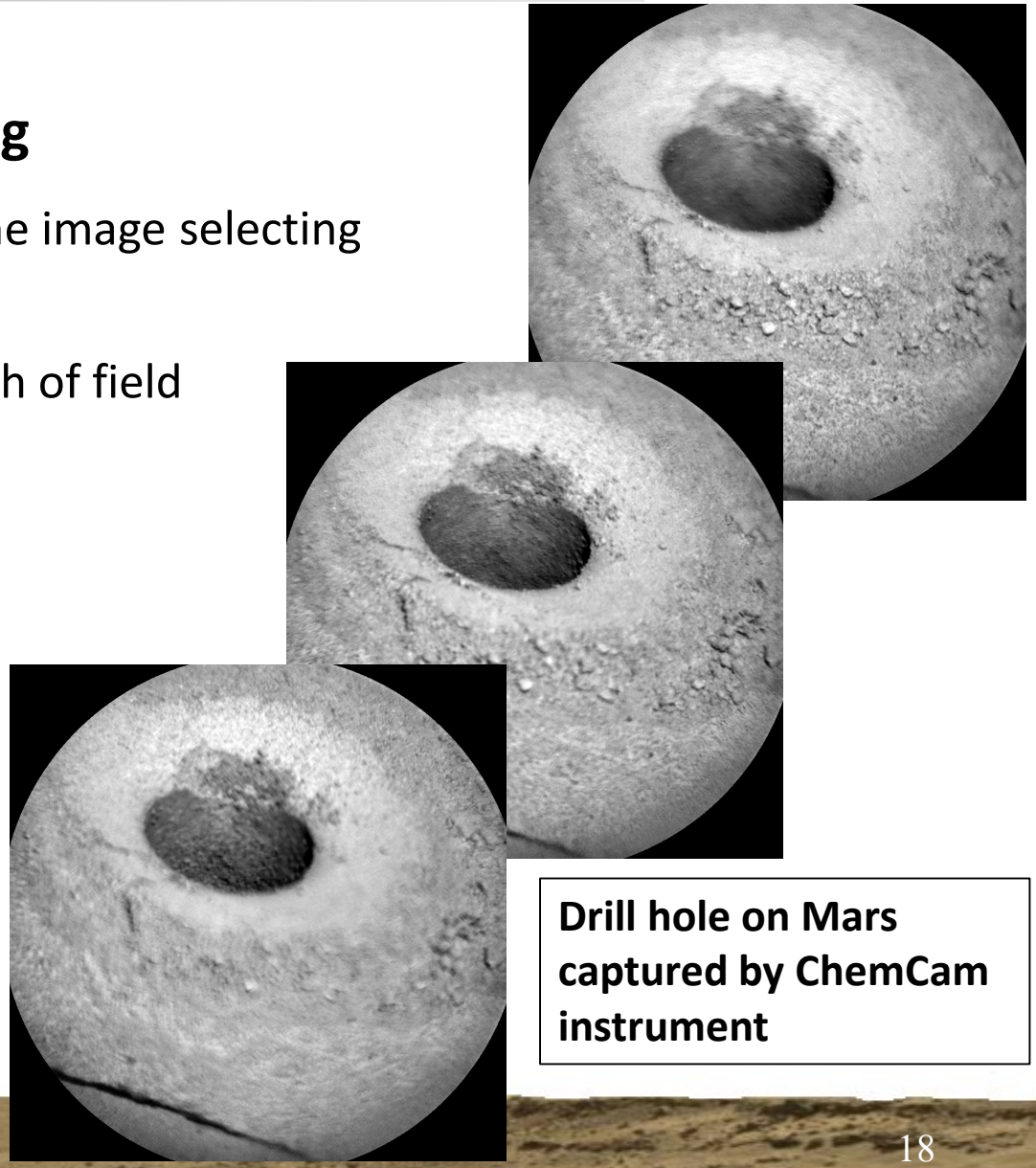


SuperCam Image Optimization

Los Alamos NATIONAL LABORATORY

Focus stacking a.k.a Z-stacking

- Combine multiple images into one image selecting the best focus for each pixel
- Resulting image has greater depth of field
- Data reduction technique, transmit fewer images
- Apply Gaussian blur and Laplacian filters to determine sharpest pixel
- Registration currently not supported, images must be very similar wrt. position and content

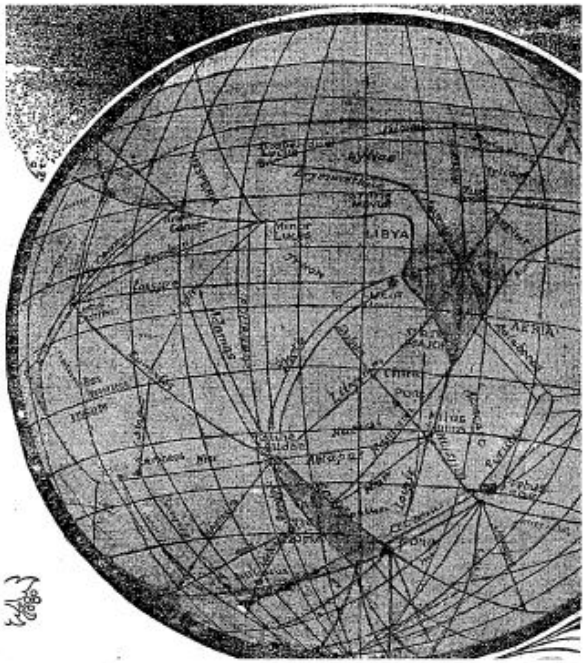


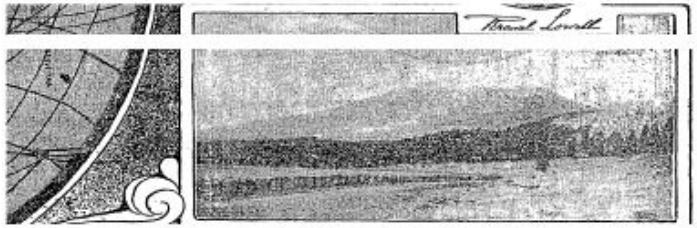
Drill hole on Mars captured by ChemCam instrument

THERE IS LIFE ON THE PLANET MARS

Prof. Percival Lowell, recognised as the greatest authority on the subject, declares there can be no doubt that living beings inhabit our neighbor world.

By Lilian Whiting.





The Peaks at Flagstaff, Arizona.

THE logicals of canals on Mars, forming a colossal and a wisely planned system designed to irrigate the oases of the vast deserts which make up the surface of this planet, are an unanswerable argument for the existence of conscious, intelligent life. A thing made predicates a maker. This truism, of course, was Paley's favorite assertion, but it is none the worse for that. Schiaparelli discovered 104 canals; Prof. Percival Lowell and his staff of the Lowell Observatory at Flagstaff, Arizona, have discovered over 350, and they regard this number as no limit. The larger and more obvious are, like the larger asteroids, discovered first; but in each opposition of the planet the trained sight and skill of the great astronomer who is now held to be the specialist on Mars—the Martian expert, as it were—discovers new and smaller ones.

yet safe to assume that the professional tea-taster can so distinguish." In fact, Prof. Lowell lays emphasis on the fact that the astronomer must see with his mind as well as with his eyes.

In consultation with Prof. W. H. Pickering and other eminent counselors the site of the new observatory, whose supreme mission was to be the study of Mars, was selected in Arizona, on account of the steadiness of the air. Flagstaff is on a plateau oasis some 7,000 feet above sea level, with the purple peaks

quickening to vegetable growth would produce the phenomena we see," says Prof. Lowell. "Set free from the Winter locking up, the water accumulated in the ice-caps evaporates, which produces the im-